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RESEARCH MEMORANDUM

EXTERNAL-STORE DRAG REDUCTION AT TRANSONIC AND LOW SUPERSONIC MACH NUMBERS BY APPLICATION OF BALDWIN'S MOMENT-OF-AREA RULE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

An investigation has been made to evaluate the external-store drag reductions obtainable by application of Baldwin's moment-of-area rule. Several wing-body combinations representative of current airplane designs were investigated with and without four typical air-to-air missiles installed. Zero-lift drag data were obtained at Mach numbers from 0.6 to 1.4 and at a Reynolds number of 1.5 million based on the mean aerodynamic chords of the models.

The results of this investigation indicate that the moment-of-area rule can be applied to external-store installations to obtain a low drag at the design Mach number of 1 and at low supersonic Mach numbers.

INTRODUCTION

Several theories have been developed in recent years which indicate methods for modifying wing-body combinations in order to obtain low wave drag at transonic and supersonic speeds. The modifications of one such method, Baldwin's moment-of-area rule (ref. 1), consist, in part, of the addition of auxiliary wing-mounted bodies of revolution. It is this feature which makes the method particularly appealing as a means of reducing the drag of aircraft fitted with external stores. The present investigation was undertaken to evaluate the results of applying the moment-of-area rule to the drag reduction of wing-body-store configurations consisting of four typical air-to-air missiles installed on several wing-body combinations representative of current airplane designs. Because of the relatively recent introduction of this method, a brief description of the moment-of-area rule and its application to the external-store problem is included in addition to the results of the investigation.

SYMBOLS

A_n	constant coefficient determined from the geometry of a configuration
C_D	total-drag coefficient
$C_{D_{wave}}$	wave-drag coefficient, $C_{D_M} - C_{D_{M=0.6}}$
C_L	lift coefficient
M	Mach number
β	speed parameter, $\sqrt{M^2 - 1}$

MOMENT-OF-AREA RULE

Theoretical Concepts

Baldwin has expressed the wave-drag equation for the supersonic area rule in a power series of the form

$$D = A_o + A_2\beta^2 + A_4\beta^4 + \ldots$$

where the constant coefficients A_o, A_2, A_4, and so forth, are independent of Mach number and depend only upon the configuration geometry, that is, upon distributions of cross-sectional area and moments of area about the longitudinal axis. In general, A_o depends only upon the area distribution, A_2 depends upon the second-moment-of-area distribution as well as the area distribution, A_4 depends upon the fourth and second-moment-of-area distributions and the area distribution, and so on. For a Mach number of 1, for which β is zero, the drag equation becomes a function of only A_o or the area distribution and thus reduces to that of the transonic area rule. As the Mach number is increased above 1 the drag becomes dependent upon the distributions of the second and higher order moments of area. The theory thus offers, in principle at least, a means of optimizing the geometry of a configuration for a Mach number of 1 in order to obtain a low wave drag at that Mach number and to obtain a low rate of increase in drag as the Mach number is increased above 1. In the applications of the moment-of-area rule made thus far, however, low drag has been obtained for only sonic and low supersonic speeds as only the distributions of area and second-moment-of-area have been optimized.

Application to Wing-Body Combinations

As an illustration of the application of the optimization procedure, consider the wing-body combination shown in figure 1. Also shown in figure 1, in solid lines, are the distributions of area and second moment of area for this basic configuration. The second-moment-of-area distribution of the body is small compared to that of the wing and is therefore neglected. The shapes of these distribution curves are not conducive to low drag in that the area distribution has a bump at the location of the wing and the second-moment-of-area distribution is short and has steep slopes. For a given volume and length the optimum shapes of the distribution curves are shown by the dashed lines. The optimum second-moment distribution is obtained by utilizing auxiliary bodies of revolution, or pods, mounted on the wing as shown on the right in figure 1. The optimum area distribution is obtained by reshaping the body after the pods have been added.

Experimental values of the zero-lift wave-drag coefficients for both the basic and the modified configurations are shown in figure 2. Also shown for comparison are experimental values of the wave drag of a similar configuration modified according to the transonic area rule. The moment-of-area-rule modification resulted in the lowest wave drag at all Mach numbers. The higher drag for the transonic area rule modification at a Mach number of 1 is believed to result from effects associated with the greater slopes of the body indentation on that configuration.

Application to Wing-Body-Store Configurations

It is evident that the auxiliary wing-mounted pods used in the moment-of-area method provide excellent positions for mounting the stores. With stores installed, an optimum or near-optimum second-moment-of-area distribution and area distribution for a complete configuration would be maintained by altering the wing pods to compensate for both these distributions of the stores. With complete success in maintaining optimum distributions, a modified configuration with stores would be expected to have not only lower wave drag than the basic configuration with stores, at transonic and low supersonic speeds, but also lower drag than the basic configuration without stores. This would be the result of reducing the interference drag between various components of the modified configuration itself as well as of reducing the interference drag due to the addition of the stores.

MODELS

In experimentally evaluating the possible benefits of the moment-of-area rule, three configurations, considered representative of current airplane designs, were selected as the parent vehicles for four typical air-to-air missiles. The configurations consisted of a high-fineness-ratio, Sears-Haack body and a thin wing with either an unswept, a swept-back, or a triangular plan form. These configurations, complete with modifications and four missiles, are shown in figure 3. The modified body of each configuration was obtained by making additions to the body, as probably would be done in modifying the fuselage of an existing airplane, rather than by making an indentation. These additions or gloves were made along the sides of the bodies rather than around the bodies (in a circular fashion) in order to simplify their fabrication. The addition of both the wing pods and body gloves increased the volume of the models by about 15 percent for the unswept wing, 11 percent for the swept wing, and 10 percent for the triangular-wing configuration. The distributions of area and second moment of area for the modified and the basic configurations are shown in figure 4. In the case of the unswept wing configuration it was possible to obtain the desired shape of the distribution curves without increasing their peak values. For the other two configurations the desired shapes were obtained at a slight cost of increases in the peak values, as shown in the lower part of figure 4.

For purposes of evaluating the results for the modified configurations, the basic configurations without missiles, and with missiles mounted in a more conventional manner were also investigated. Several of the basic configurations with conventional missile installations are shown in figure 5. In one case the missiles were mounted so that they were unstaggered in the streamwise direction. In the other cases the missiles were staggered streamwise in order that the addition of the missiles would provide at least a limited improvement in the distributions of area and second moment of area. This is demonstrated at the top of figure 6 for the unswept-wing configuration.

TESTS

Tests of the basic and modified configurations with and without missiles were conducted in the Ames 2- by 2-foot transonic wind tunnel at Mach numbers from 0.6 to 1.4 and at a Reynolds number of 1.5 million based on the mean aerodynamic chords of the models. A turbulent boundary layer was artificially produced on each configuration with the aid of boundary-layer transition strips in order to permit, with a minimum degree of uncertainty, evaluation of the wave drag of each configuration from its total-drag measurements.

RESULTS AND DISCUSSION

The results of the total-drag measurements for the unswept-wing configurations are presented in figure 7. Note the reductions in drag obtained by merely staggering the conventionally mounted missiles in the streamwise direction. Of all the configurations with missiles, the modified configuration had the lowest total drag at all Mach numbers above 0.94. At subsonic speeds the higher drag of the modified configuration is directly attributable to the skin-friction drag of the increased surface area associated with the added volume of the wing pods and the body glove. The total-drag results for the sweptback- and the triangular-wing configurations are shown in figure 8. Each of the modified configurations with missiles had lower total drag at transonic speeds than did each of the corresponding basic configurations with the staggered conventional missile installations. Unlike the unswept-wing configurations, however, at subsonic Mach numbers below 0.9 and at supersonic Mach numbers above 1.2 there was little difference in the drag.

In considering these total-drag results in terms of full-scale airplanes, it is, of course, important to take into account the effect of Reynolds number on the skin-friction drag components. In view of the fixed transition of the boundary layer at the low Reynolds number of this investigation, and the probable natural transition at flight Reynolds numbers, the skin-friction drag penalty for a modified configuration at flight Reynolds numbers would be expected to be less than that observed here.

The wave-drag components of these total-drag measurements, however, would be expected to be directly applicable at flight Reynolds numbers. In evaluating the wave-drag components, the usual procedure was followed of assuming that the subsonic level of the drag at 0.6 Mach number is a good measure of the skin-friction drag throughout the speed range of this investigation. This is believed to be a good assumption in the present case because of the fixed transition provided. The resulting wave-drag values for the unswept-wing configuration are presented in figure 9.

As was pointed out previously, complete success in the application of the method would be expected to result in a modified configuration with missiles having less wave drag than the basic configuration without missiles. This expectation was achieved in the case of the unswept wing only near sonic speed. (See fig. 9.) The wave-drag results for the swept- and triangular-wing configurations are shown in figure 10. These modified configurations with missiles had essentially the same or higher wave drag than the corresponding basic configurations without missiles. This result is believed to be partially due to the increased peak values of the distributions of area and second moment of area shown in figure 4 for these modified configurations.

The effectiveness of the moment-of-area rule in reducing the drag of external-store installations has been demonstrated thus far by comparing the results for the modified configurations with missiles, and those for the corresponding basic configurations without missiles. An equally important comparison is that between the modified and basic configurations with missiles installed in both cases. It is evident from the results for all three wing plan forms that the missile installation on the modified configuration is a decided improvement over the conventional installation on the basic configuration. For example, at sonic speed, the wave drag of each modified configuration with missiles was about one-half that of the corresponding basic configuration with the staggered conventional missile installation. (See figs. 9 and 10.)

A major source of this improvement of the modified configuration with missiles over the basic configuration with missiles was the reduction of the interference drag due to the addition of the missiles. This is clearly demonstrated in figure 11. Shown for each of the three wing plan forms is the wave drag due only to the addition of four missiles to both the basic and the modified configurations. Also shown, in dashed lines, to provide a measure of the interference drag is four times the wave drag of one isolated missile. These data indicate that the addition of the missiles to each of the modified configurations resulted in an installation wave drag of about the same order of magnitude as the wave drag of the missiles alone; whereas the wave drag of the conventional installations was approximately three and six times greater, respectively, for the conventional staggered and unstaggered missile installations.

CONCLUSIONS

The principal conclusions obtained from this investigation of external-store drag reduction at transonic and low supersonic speeds by application of the moment-of-area rule are as follows:

1. The drag of a wing-body-store configuration can be substantially reduced at the design Mach number of 1 and at low supersonic Mach numbers by modifying the complete configuration according to Baldwin's moment-of-area rule.

2. In cases where the indicated modifications are not feasible, drag reductions can also be realized by relocating the stores in positions which more nearly satisfy the moment-of-area rule.

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Moffett Field, Calif., Nov. 1, 1955

REFERENCE

1. Baldwin, Barrett S., Jr., and Dickey, Robert R.: Application of Wing-Body Theory to Drag Reduction at Low Supersonic Speeds. NACA RM A54J19, 1955.

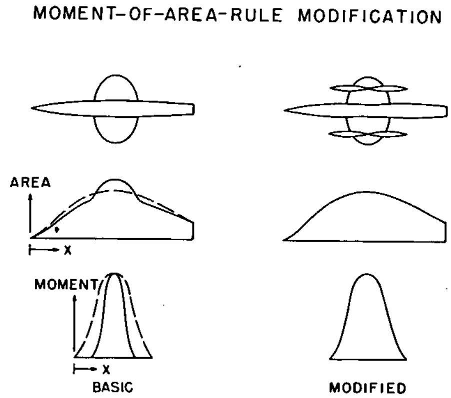

Figure 1

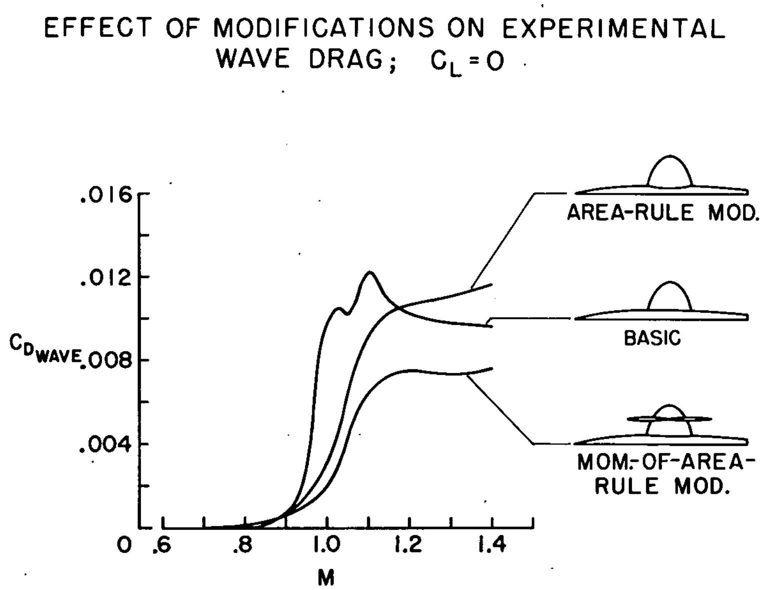

Figure 2

MODIFIED CONFIGURATIONS WITH MISSILES

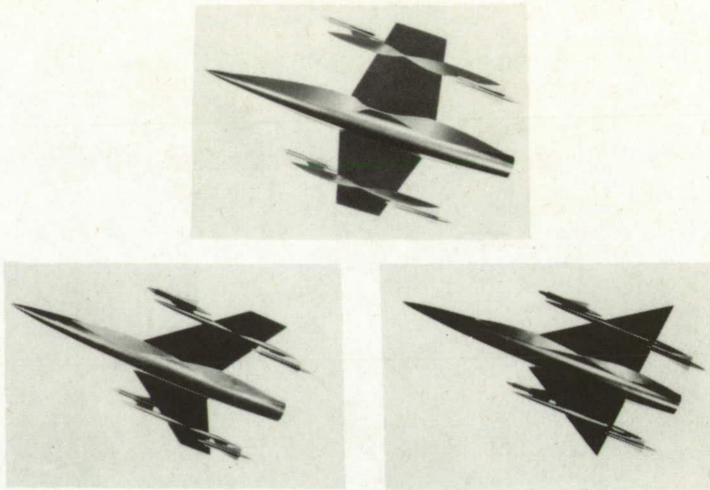

Figure 3

AREA AND MOMENT DIAGRAMS FOR MODIFIED CONFIGURATIONS WITH MISSILES

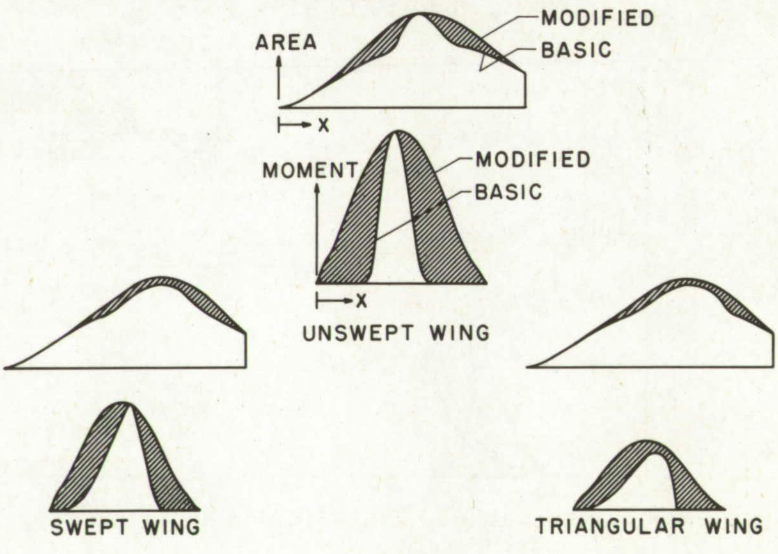

Figure 4

BASIC CONFIGURATIONS WITH CONVENTIONAL MISSILE INSTALLATIONS

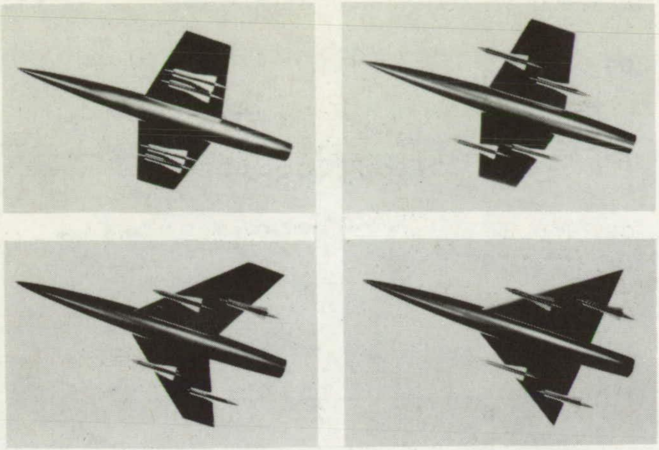

Figure 5

AREA AND MOMENT DIAGRAMS FOR BASIC CONFIGURATIONS WITH CONVENTIONAL MISSILE INSTALLATIONS

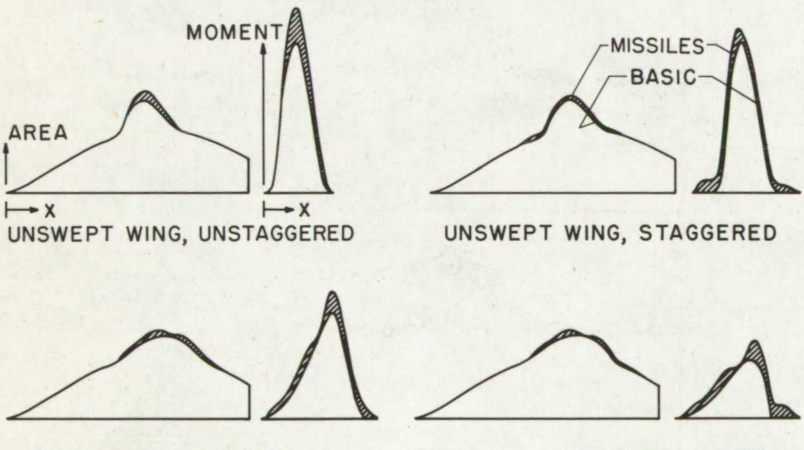

Figure 6

TOTAL DRAG OF UNSWEPT-WING CONFIGURATIONS; $C_L = 0$

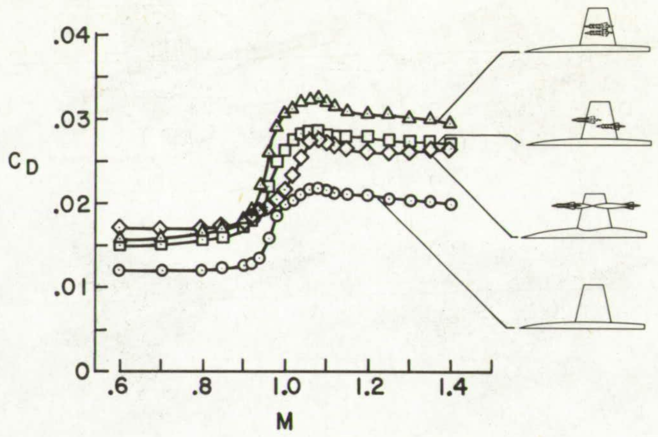

Figure 7

TOTAL DRAG OF SWEPT- AND TRIANGULAR-WING CONFIGURATIONS; $C_L = 0$

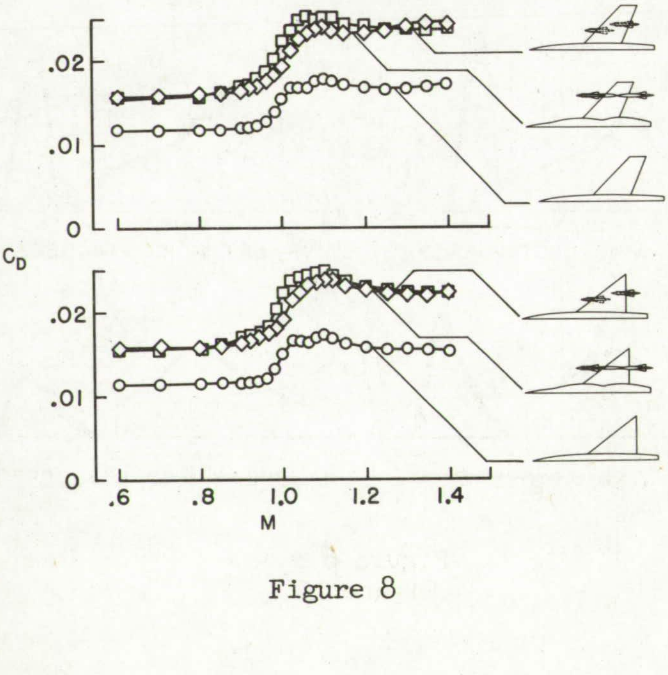

Figure 8

WAVE DRAG OF UNSWEPT-WING CONFIGURATIONS; $C_L = 0$

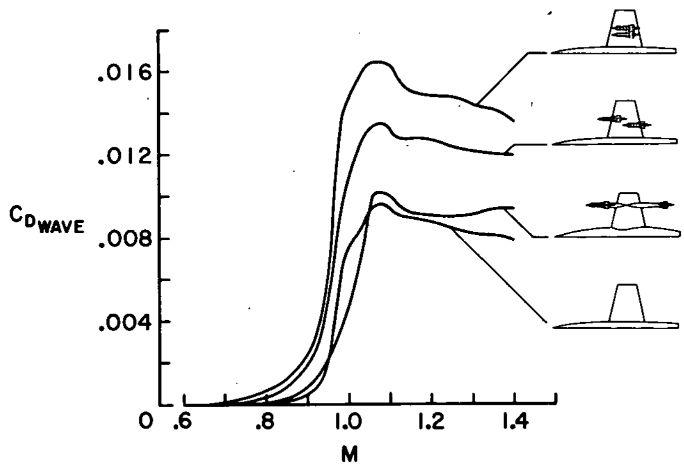

Figure 9

WAVE DRAG OF SWEPT-AND TRIANGULAR-WING CONFIGURATIONS; $C_L = 0$

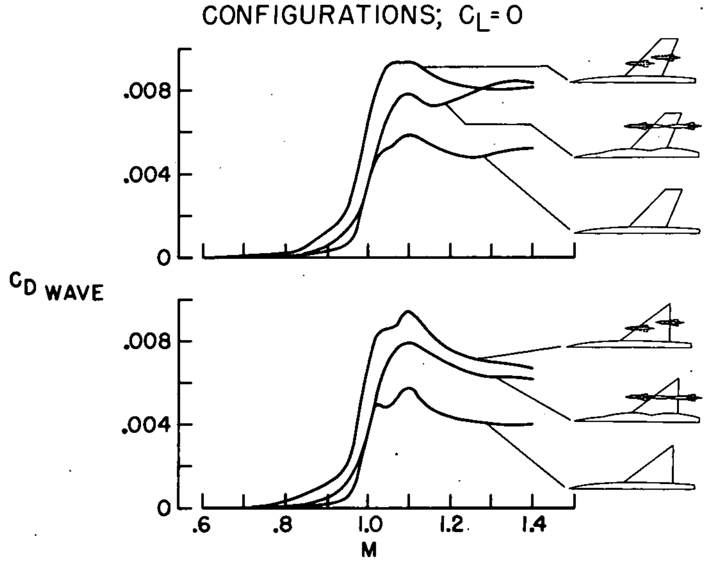

Figure 10

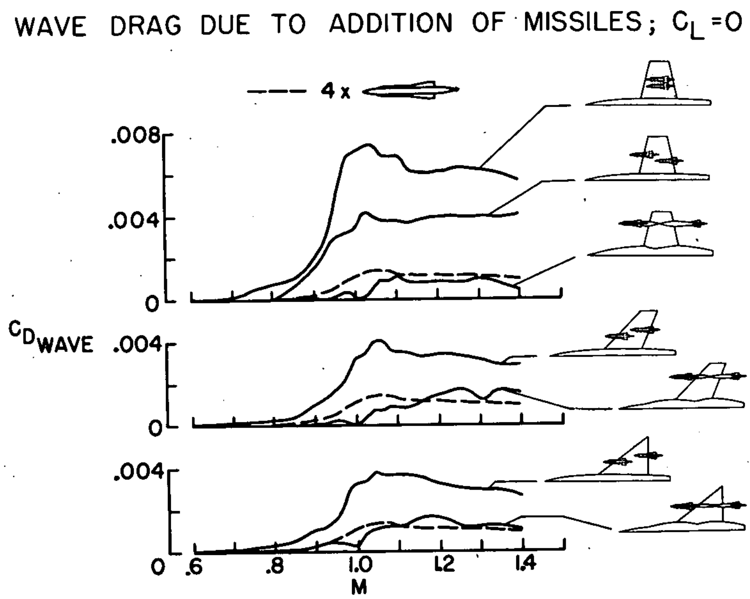
WAVE DRAG DUE TO ADDITION OF MISSILES; C_L =0
4 x
.008
.004
0
$C_{D_{WAVE}}$
.004
0
.004
0
.6
.8
1.0
1.2
1.4
M

Figure 11